AirTouch: Mobile Gesture Interaction with Wearable Tactile Displays

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AirTouch: Mobile Gesture Interaction with Wearable Tactile Displays

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Abstract

AirTouch is a wrist-based gesture interface that enables mobile gesture interaction under limited visual attention settings. Since the original Gesture Watch lacked non-visual feedback, visual attention was required. AirTouch addresses this visual distraction issue by adding tactile feedback. The tactile feedback is supported by a new push-to-gesture (PTG) mechanism, which gives the user the ability to cancel the gesture input and causes less fatigue compared to the previous mechanism. A user study was conducted to observe the effect of the tactile feedback and the new PTG. The results show that the added tactile feedback enables more accurate and faster interaction. We also found that the tactile feedback successfully compensates for limited vision. The perceived difficulties and performance time with tactile display under limited vision was similar to having full visual attention without tactile display.

Introduction

The growing popularity of mobile devices gives people a new way to use computing devices. Traditional mobile computing interfaces such as button and touch interfaces are designed to be used while the user is stationary. Operating such an interface often causes distractions, especially visual distractions, on people's primary tasks. With fast, forward-moving technology, mobile devices are getting increasing portable. This reduction in form factor also causes user interfaces to shrink. A smaller user interface requires precise hand-eye coordination, resulting in an increase in user distraction. Such visual distractions pose serious safety threats when the user is mobile, which could result in fatalities.

One approach to this issue is a gesture interface. The gesture interfaces use large gestures performed by moving a user's hand or fingers over a relatively large interaction space. This approach improves usability greatly by moving the interaction area from small physical buttons and touch surfaces to a large space above the device. The user can interact with the device in a large virtual interaction pane rather than by pinpointing tiny buttons. The original Gesture Watch [3] uses such a gesture interface. It utilizes four proximity sensors to capture in-air hand gestures. Placing the gesture interface on the wrist means that it is glance-able and enables faster access [1]. During the original Gesture Watch study [3], participants were able to use the gesture watch with very minimal training. The gesture recognition accuracy was above 90% while users were walking outdoors. Even though the Gesture Watch achieved promising results, it still had several issues. Despite the use of a gesture interface, the Gesture Watch still required visual attention to ensure the exact hand placement while performing the gesture. The Gesture Watch trigger mechanism requires tilting the wrist upwards for the entire duration of the gesture. This mechanism causes physical fatigue on the user's wrist. The original gesture watch also makes it impossible for the user to cancel an incorrect gesture once it has been performed.

In order to address the visual distraction and fatigue issues that were discovered in the original gesture watch, we designed the AirTouch. Our solution is to add a tactile display that provides non-visual feedback, thus avoiding potential visual distraction. The AirTouch couples each sensor with one shaft-less vibration motor (diameter = 10mm, height = 3.4mm). The vibration motor is synchronized with the sensor, providing a preview of the in-air hand gesture without the need for visual attention. We also designed a new trigger mechanism to address the fatigue issue in the original mechanism. Now, tilting the wrist is needed only to confirm the gesture after previewing it via tactile feedback. Users can also cancel gesture input by not tilting their wrist within the confirmation time period.

Related work

Quickdraw by Ashbrook et al. [1] explored the impact of mobility and various on-body placements on device access time. The study examined three different mobile device placements on the body: in the pocket, on the hip in a holster, and on the wrist. Each placement was tested with two corresponding conditions: walking and standing still. During the study, each condition started with an alert that was generated by the mobile device (Motorola E680i camera phone). In response, participants needed to unlock the device after retrieving it. Participants then selected the number previously displayed on the lock screen from a group of four. In the study, pocket placement and hip placement yielded 68% and 98% longer access time respectively, than wrist placement. (Access time is defined as the time required for the user to begin unlocking the device after the alarm has started.) For the two non-wrist based placements, 78% of the access time was consumed getting the device out of the pocket or holster. A wrist-based interface requires significantly less access time, which is an important factor in deciding whether or not to use the device.

The predecessor of the AirTouch is the Gesture Watch project [3]. The Gesture Watch is a wrist-worn mobile gesture interface that uses non-contact hand gestures to control electronic devices. It uses four proximity sensors to capture the user's in-air hand gestures. It also has one proximity sensor facing towards the user's hand that can detect whether the user's wrist is tilted upwards. This sensor acts as a trigger sensor. The user turned on the watch by tilting his wrist to block the proximity sensor and thus inform the system of the start of the gesture. The user then performed the gesture while keeping his wrist tilted. Next, the user lowered his tilted wrist to complete the gesture. The system then interpreted and recognized the gesture.

The Gesture Watch achieved promising results. The recognition accuracy was above 90% in mobile outdoor conditions. Since the gesture watch did not provide any feedback to the user, the user had to rely on visual feedback to confirm of correct hand-sensor alignment.

In addition to the gesture interface, a wristwatch-based touchscreen interface has also been explored [2]. The touchscreen wristwatch uses a round watch face and places buttons around the perimeter of the circular screen. Three different interaction methods were explored: Tapping buttons placed on edge of the screen, sliding in a straight line between buttons, and sliding from target to target around the rim. Fifteen participants were recruited, and each completed 108 tasks. From the study, mathematical models were developed for error rate, given interaction method and button size. For instance, 90% of the central area would be reserved for display, given that an error rate of 5% is desired on a ten button interface. In the study, targets in the upper left region -- from 9 o'clock to 12 o'clock were likely to be obscured by users' fingers. Also, targets in the bottom of the watch were difficult to hit due to finger shape.

Various studies have been done using tactile displays to provide feedback [4, 5]. A Wearable Tactile Display (WTD) created by the BuzzWear [4] project was developed to eliminate the need for visual attention for providing feedback. BuzzWear explores the difficulties in identifying 24 tactile patterns on the wrist by manipulating four factors – intensity of vibration, starting point, temporal pattern and direction - under different conditions. Two experiments were conducted in the study. The first experiment focused on people's ability to perceive different tactile patterns. The second experiment explored the effect of the WTD under visually distracted conditions. Participants were able to perceive 24 different tactile patterns easily after 40 minutes of training. Their performance in the visually distracted condition did not decrease. The BuzzWear study concluded that wrist-worn tactile displays might be effective for implementing mobile interface.

Improving the Form Factor Design of Mobile Gesture Interface on the Wrist by Deen et al [7] explores different design factors of on-wrist gesture interface placements.

This paper presents the design iteration process of the Gesture Watch with tactile feedback. The design challenges were broken down into wear-ability, mobility, and tactile perception. These factors were studied using sensor housing, strap, and motor housing configurations. In the first design iteration, all components were oriented on the upper side of the arm. In the second design iteration, the tactile display was moved to the lower side of the wrist in order to control tightness. Also, the sensor housing and strap were redesigned to improve the overall wear-ability and mobility. Through several design iterations, various issues in form factor design were improved and others will continue to be investigated further.

Despite having the benefits of wrist-based gesture interface, users of the Gesture Watch still relied on visual feedback to know when the proximity sensors would be triggered. The AirTouch addresses this visual distraction issue of the original Gesture Watch by adding a tactile display. A new trigger mechanism is designed to solve the fatigue issues of the old mechanism. Together, these features provide a preview of in-air gestures through tactile feedback to facilitate reversible, error-free, and low distraction mobile gesture interaction.

Implementation

The AirTouch consists of two parts: the watch and the tactile display. Like the original Gesture Watch [3], the AirTouch watch uses four SHARP GP2Y0D340K infrared (IR) proximity sensors to capture the user's in-air hand gestures. These IR sensors have a range of 10 – 60 cm and are designed to operate in areas with other IR light sources, such as sunlight. The sensor outputs a digital high while not detecting objects within the range, and a digital low when an object is detected. The sensors are arranged in an X shape (Figure 1), which is optimized for the tactile display. A fifth sensor (the confirmation sensor) is placed at the front of the watch, facing towards the

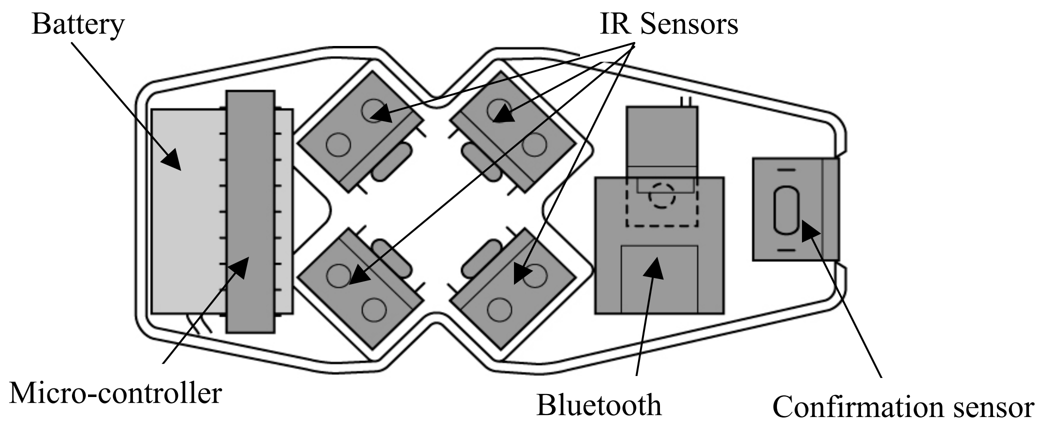


Figure 1. AirTouch internal components

user's hand. The fifth sensor tilts approximately 20 degrees away from the wrist to avoid false triggering.

Data from the proximity sensors are passed to an ATmega 168 micro-controller (Figure 1). The micro-controller stores sensor data and turns on the tactile display based on the sensors' input. The micro-controller also controls the vibration motors through a

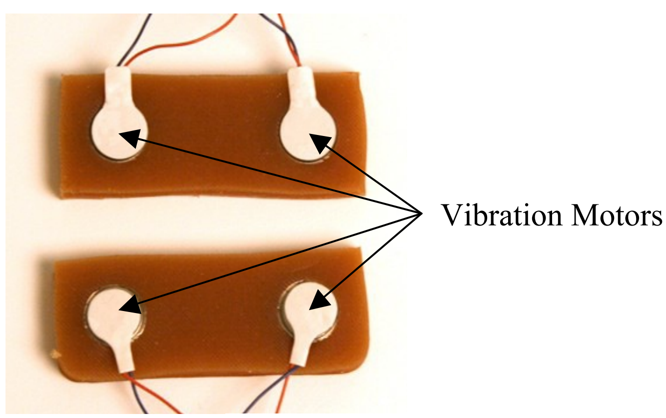


Figure 2. Tactile display.

transistor array. After the user has finished his hand gesture, the micro-controller transmits the gesture data only if the user confirms the gesture input within the two seconds confirmation period. Stored sensor data is discarded after the confirmation period times out, allowing the user to cancel incorrect gesture inputs by not triggering the confirmation sensor.

The tactile display consists of four vibration motors (Figure 2) contained in two rubber housings. Each motor is paired with one IR sensor. The micro-controller turns on vibration motors based on the sensors' input. It also synchronizes the gesture input and

Figure 3. New push to gesture mechanism

tactile display, providing the user with a tactile feedback of the in-air gesture. Power is supplied by a 3.7 V Lithium-ion battery. A power regulator is used to guarantee a stable 3.3 V power supply and ensure that the intensity of vibration remains consistent as the battery discharges.

To input gestures to AirTouch, the user uses a push-to-gesture mechanism (Figure 3). Unlike the original push-to-gesture mechanism in the Gesture Watch, the user does not need to tilt his or her wrist to start the process. The user simply starts performing the input gesture in the interaction space. While the user performs the gesture, the tactile display provides the user feedback of the in-air-gesture. Tilting the wrist triggers the confirmation sensor, which in turn tells the system to send the gesture for recognition and processing.

A remote computer connects to the watch over Bluetooth and processes the sensor data through the gesture recognition process. Gesture recognition software (Figure 4) is

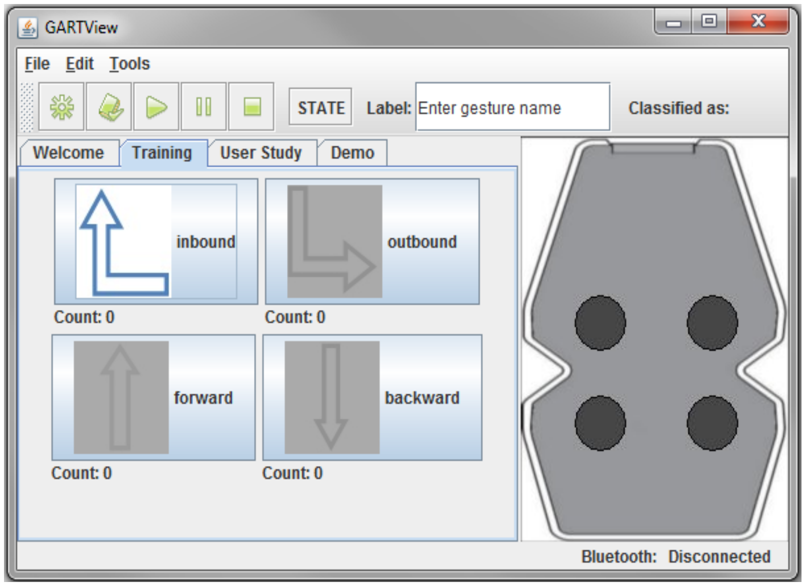


Figure 4. Software interface

implemented using the Gesture and Activity Toolkit (GART) [6]. GART uses the Hidden Markov Model from Cambridge University for training and recognition. Each participant trains the recognition system to generate a personalized gesture library in the beginning of the study. GART then uses this library for optimal real-time gesture recognition. Gesture software also logs each set of sensor data with a time stamp to be used for later analysis. At the end of the recognition process, GART matches the sensor data with one of the pre-defined gestures and outputs the recognition result. The result is then used by different modules; the demo module maps each gesture to a specific function (for example, play/pause in a music player) and the user study module logs the result for later data analysis.

Task and Procedure

In order to study the efficacy of the tactile feedback, a formal user study was run. Sixteen participants were recruited for the study from the Georgia Institute of Technology (mean age = 24.25, three female, thirteen male) The average circumference of the user's wrists was 165.81mm, and the average width of the user's wrists was 56.26mm. All participants except one were right-handed. Additionally, 37.5% of the participants reported wearing a wristwatch on a daily basis. User performance accuracy and performance time were also measured during the experiment. The performance time was

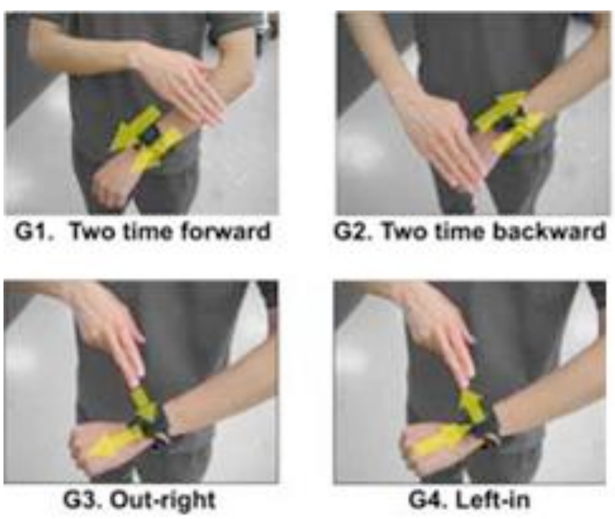


Figure 5. Four gestures designed for the study.

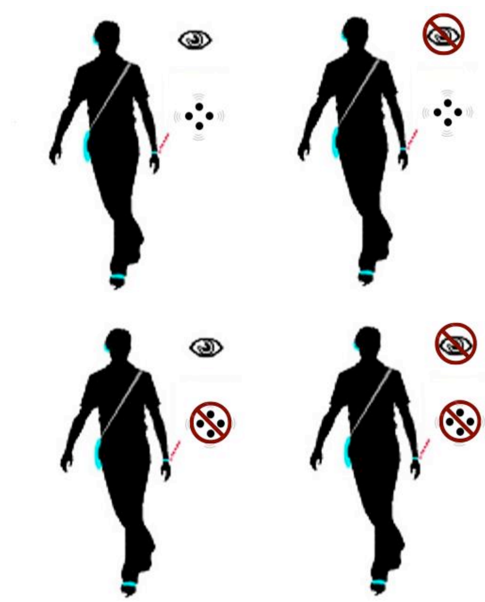


Figure 6. 2x2 conditions.

then broken further into gesture time and confirmation time. Gesture time measures that time between the first and last sensor data, and confirmation time measures the last sensor data and the confirmation event (either confirmation or abort).

During the study, every participant wore headphones, a backpack and the

AirTouch system on their non-dominant wrist. A computer was placed in the backpack that was connected to the AirTouch system during the study. It ran the gesture recognition process, logged the sensor data, and gave the participant voice commands through the headphones. Subjective feedback from NASA-TLX and surveys were also collected at the end of the study.

The study began with a training session, in which the participants learned about the four gestures designed for the study. After learning about the gestures, each participant then trained the gesture recognition system to generate a calibrated personalized recognition library (Figure 5).

The primary section of the study started after the training session. It consisted of four conditions, arranged as a 2x2 within-users study (Figure 6). A half-blocked pair of goggles was worn to simulate limited vision around the wrist area (Figure 7). For each

Figure 7. Half blocked goggle

condition, the participant walked around a track in the laboratory (Figure 8). The track is approximately 26 meters long and the participant was guided with flags hanging from the ceiling.

Each condition consisted of 24 trials arranged in a random order with a random delay between them. Each trial started with a voice command asking the participant to

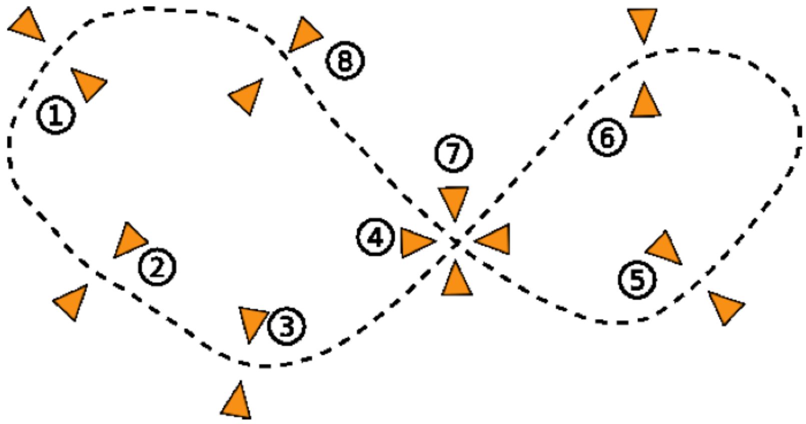
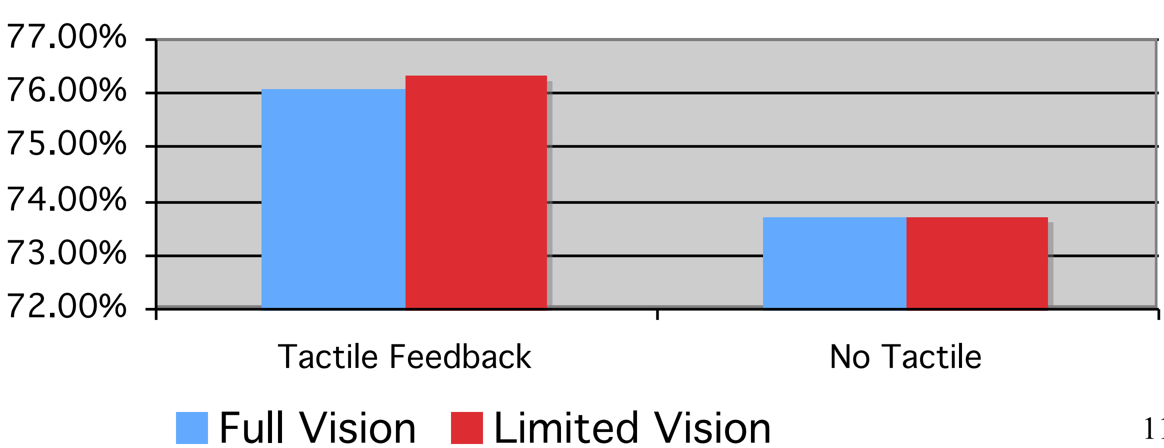


Figure 8. In-lab walking track path

perform one of the four gestures. In response, the participant performed the gesture and confirmed it. All sensory data was logged and sent to GART for gesture recognition. Accuracy and performance time were measured during the study.

Results

The average accuracy of the training session was 93.97%. Compared to the training section, the accuracy is relatively low in the primary section (60-80%). The accuracy in the sections that had tactile feedback was slightly higher than the sections that had no tactile feedback regardless of the visual condition (Figure 9). However, a



paired t-test showed that there is no statistical significance in this difference. The effect of visual restriction was not statistically significant. The result of one-way analysis of variance (ANOVA) showed that the type of gesture affects accuracy across all four conditions ($p < 0.05$).

The tactile feedback had different effects in performance time in both full and

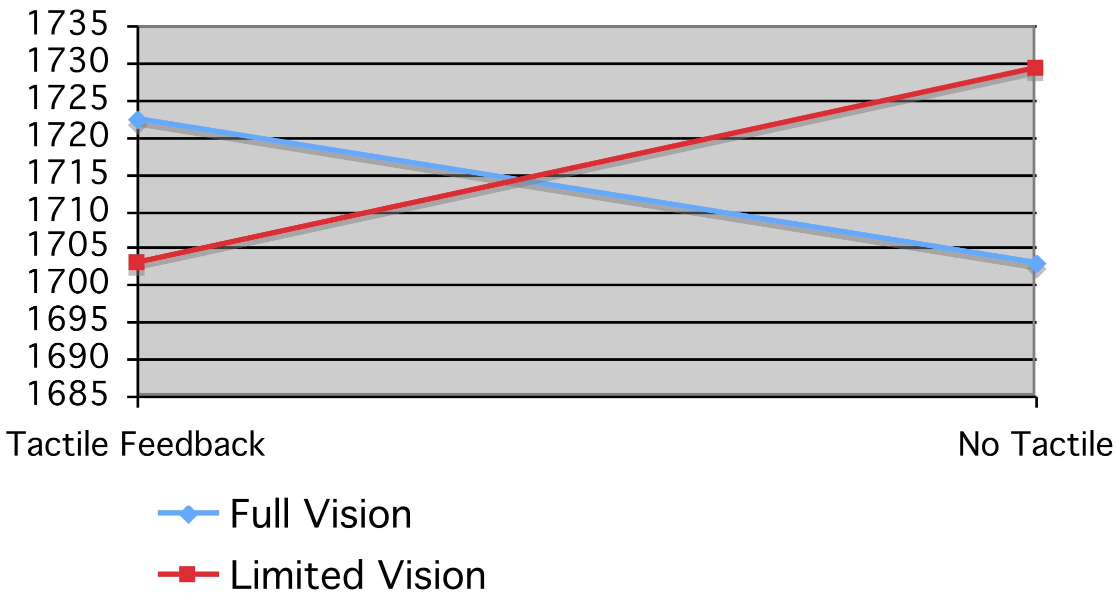


Figure 10. Four condition performance time (ms)

limited vision condition. Tactile feedback enabled faster performance time in the full vision condition (Figure 10). The effect was again not statistically significant ($p = 0.052$). However, tactile feedback enabled faster performance time with statistical significance in the limited vision condition ($p = 0.011$). This result shows that tactile feedback has a larger effect when vision is limited. The effect of restricting visual attention was statistically significant with tactile feedback ($p = 0.046$) and without ($p = 0.012$). The trend (Figure 9) was observed consistently in both gesture time and confirmation time. However, the trends observed in gesture time and confirmation time were not statically significant.

Subjective feedback showed that restricted vision increased the level of difficulty regardless of the presence of tactile feedback. However, participants reported that having tactile feedback made their tasks easier by increasing their confidence in both full and limited vision conditions. The perceived difficulties of limited vision with tactile feedback were close to the perceived difficulties of full vision without tactile feedback. These results suggest that tactile feedback compensates for the limited vision.

Discussion and Future Work

Comparison between performance time of no tactile full vision and tactile limited vision showed that tactile feedback could somewhat compensate for limited vision. Two limitations, which were caused by the test setting and hardware, were observed during the study. The first is that the indoor walking track does not simulate the chaos and unpredictability of the real world environment. Some participants reported only using vision to navigate around the track in full vision settings, while others reported shifting

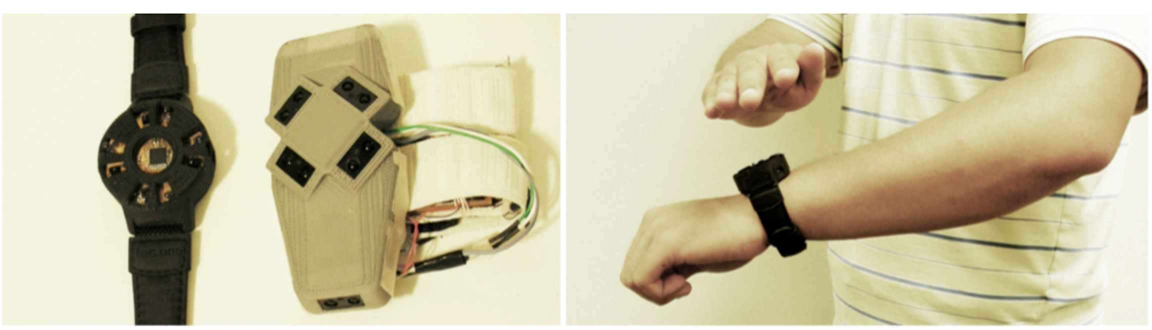


Figure 11. AirTouch design iterations.

their visual attention between walking and the wrist. This indicates that the user's vision was not controlled as it was intended. Also, the sensors' range needs to be shortened.

Depending on participants' body posture, which is less consistent while walking than standing, sensors occasionally detected the participants' chest or upper forearm and caused false triggering. The false triggering unintentionally begins the time out period count, and the attempts were sometimes aborted before the participants started applying gestures. Even though this artifact did not directly affect the accuracy of the study, participants reported frustration over the falsely triggered abort messages. In order to address this hardware limitation, we designed and implemented a new AirTouch prototype.

The new AirTouch is significantly smaller physically (46.5mm x 17mm x 45mm) (Figure 11). Instead of pre-package IR proximity sensors, we implemented custom analog IR proximity sensors. The analog sensors can also provide hand – watch distance, giving us full control over sensor range and could potentially expand the number of supported gesture types. On the new prototype, the sensor layout was re-rotated to cardinal arrangement to enable better gesture recognition. Further investigation is required to iterate the hardware, gesture design, and study design.

Conclusion

The tactile feedback enables more accurate and faster interaction under limited visual attention settings. The perceived difficulties and performance time with tactile display under limited vision was similar to having full visual attention without tactile display. Also, the new push-to-gesture mechanism reduces physical fatigue compared against the old mechanism and gives the user the ability to cancel gesture input. Thus, we conclude that tactile feedback can successfully assist mobile device interaction in limited visual settings.

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